LMSC-HEC TR F268584-IIIB

FINAL REPORT

SPACE SHUTTLE MAIN ENGINE STRUCTURAL ANALYSIS AND DATA REDUCTION/EVALUATION

VOLUME 3B: HIGH PRESSURE FUEL TURBO-PUMP PREBURNER PUMP BEARING ASSEMBLY ANALYSIS

April 1989

Contract NAS8-37282

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER, AL 35812

by

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Rebeca S. Violett

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FOREWORD

This final report summarizes the analysis performed on the HPOTP Preburner Pump Bearing assembly located on the Space Shuttle Main Engine. An ANSYS finite element model for the inlet assembly was built and executed by Gloria B. Power and Rebeca S. Violett in the Structures & Mechanics Section of the Lockheed-Huntsville Engineering Center under Contract NAS8-37282. Thermal and static analyses were performed by Rebeca S. Violett.

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1. INTRODUCTION

The high-pressure oxidizer turbo-pump (HPOTP) consists of two single-stage centrifugal pumps, the main pump and the preburner pump, that are directly driven by a two-stage hot-gas turbine. The main pump supplies the preburner pump with liquid oxygen. The pump-end bearings are cooled by liquid oxygen flowing from the preburner pump through the hub seal to the bearings and then to the main pump inducer/impeller inlet.

Thermal and static analyses were performed on the HPOTP preburner pump bearing assembly to calculate the radial displacements of the assembly components. The static analysis load case consisted of thermal loads (obtained from the thermal analysis), interference fits, pressure loads, and bolt preloads.

An ANSYS three-dimensional finite element model was generated to perform the thermal and stress analyses. The model was generated on Lockheed's VAX 11/785 computer and executed on the Marshall Space Flight Center's Engineering Analysis and Data System (EADS).

The remaining sections of this report consist of descriptions of the model, boundary conditions and loads, material properties, thermal environment, thermal analysis, structural analysis, and recommendations.

2. MODEL DESCRIPTION

A finite element, cyclic symmetric model of a 40° sector of the HPOTP preburner pump bearing assembly was generated using ANSYS. The 40° section is defined from $\theta=0°$ to $\theta=40°$ in a cylindrical coordinate system with its origin located at the center of the HPOTP volute. Figure 1 is a hidden line plot of the ANSYS finite element model. In this and all the remaining plots in this section, the view is from the pump end to the turbine end of the HPOTP. The preburner pump bearing assembly model consists of six components: the isolator, the isolator bolts, the hub seal, the hub seal retainer ring, the notched head screw, and the housing support. Figure 2 shows cutaway views of all these components.

Lists of the model components, identification of the element material and type numbers, and a count of the number of nodes and elements of each listed component appear in the tables that follow. Table 1 applies to the heat transfer thermal analysis, and Table 2 applies to the structural static analysis. The radial and axial gap elements are null for the thermal analysis, while the convection link elements are null for the static analysis. The element type number information is useful for selecting all the nodes and elements in a component. For example, to select all the isolator nodes and elements, the following ANSYS commands would be issued:

```
ERSEL,TYPE,1
NELEM
```

These command can be issued in either the PREP7 or POST1 routines.

Table 1 THERMAL ANALYSIS NODES, ELEMENTS, AND TYPE NUMBERS FOR COMPONENTS

Component	Drawing No.	Mat. No.	Nodes	Elements	Elem. Type No.
Isolator	RS007933-023	1	778	466	1
Isolator Bolts (2)	R0011320-005	4	126	72	2
Hub Seal	RS007766-023	3	371	184	3
Retainer Ring	RS007761-009	2	389	222	4
Notched Head Screw	RS007792-003	4	96	72	5
Housing Support	RS007937-007	1	730	434	6
Convection Links		7 through 9		368	7 through 9
Radial Gaps					0
Axial Gaps					0
TOTAL			2490	1818	

Table 2 STATIC ANALYSIS NODES, ELEMENTS, AND TYPE NUMBERS FOR COMPONENTS

Component	Drawing No.	Mat. No.	Nodes	Elements	Elem. Type No.
Isolator	RS007933-023	1	778	466	1
Isolator Bolts (2)	R0011320-005	4	126	72	2
Hub Seal	RS007766-023	3	371	184	3
Retainer Ring	RS007761-009	2	389	222	4
Notched Head Screw	RS007792-003	4	96	72	5
Housing Support	RS007937-007	1	730	434	6
Convection Links		7 through 9			0
Radial Gaps				124	11,12,16
Axial Gaps				173	13-15,17,18
TOTAL			2490	1747	

Tables 3 and 4 provide a complete description of the element types, including the elements' optional parameters (KEYOPT), for both the thermal and static analyses.

Table 3 MODEL ELEMENT TYPES FOR THERMAL ANALYSIS

No.	Type	KEYOPT	Description
1	70	0 0 0 0 0 0 0 0 0 0	ISOPAR. SOLID, THERMAL
2	70	0 0 0 0 0 0 0 0 0 0	ISOPAR. SOLID, THERMAL
3	70	0 0 0 0 0 0 0 0 0 0	ISOPAR. SOLID, THERMAL
4	70	0 0 0 0 0 0 0 0 0 0	ISOPAR. SOLID, THERMAL
5	70	0 0 0 0 0 0 0 0 0 0	ISOPAR. SOLID, THERMAL
6	70	0 0 0 0 0 0 0 0 0 0	ISOPAR. SOLID, THERMAL
7	34	0 0 0 0 0 0 0 0 0 0	ISOPAR. SOLID, THERMAL
8	34	0 0 0 0 0 0 0 0 0 0	CONVECTION LINK
9	34	0 0 0 0 0 0 0 0 0 0	CONVECTION LINK
10	34	0 0 0 0 0 0 0 0 0 0	CONVECTION LINK
11	0		NULL
12	0		NULL
13	0		NULL
14	0		NULL
15	0		NULL
16	0		NULL
17	0		NULL
18	0		NULL

Table 4 MODEL ELEMENT TYPES FOR STATIC ANALYSIS

No.	Type	KEYOPT	Description
1	45	0 0 0 0 0 0 0 0 0 0	ISOPAR. STRESS SOLID, 3-D
2	45	0 0 0 0 0 0 0 0 0 0	ISOPAR. STRESS SOLID, 3-D
3	45	0 0 0 0 0 0 0 0 0 0	ISOPAR. STRESS SOLID, 3-D
4	45	0 0 0 0 0 0 0 0 0 0	ISOPAR. STRESS SOLID, 3-D
5	45	0 0 0 0 0 0 0 0 0 0	ISOPAR. STRESS SOLID, 3-D
6	45	0 0 0 0 0 0 0 0 0 0	ISOPAR. STRESS SOLID, 3-D
7	45	0 0 0 0 0 0 0 0 0 0	ISOPAR. STRESS SOLID, 3-D
8	0		NULL
9	0		NULL
10	0		NULL
11	40	0 0 0 0 0 0 0 0 0 0	COMBINATION ELEMENT
12	40	0 0 0 0 0 0 0 0 0 0	COMBINATION ELEMENT
13	40	0 0 3 0 0 0 0 0 0 0	COMBINATION ELEMENT
14	40	0 0 3 0 0 0 0 0 0 0	COMBINATION ELEMENT
15	40	0 0 3 0 0 0 0 0 0 0	COMBINATION ELEMENT
16	40	0 0 0 0 0 0 0 0 0 0	COMBINATION ELEMENT
17	40	0 0 3 0 0 0 0 0 0 0	COMBINATION ELEMENT
18	40	0 0 3 0 0 0 0 0 0 0	COMBINATION ELEMENT

All elements listed in Tables 1 and 2 are stored in a single ANSYS FILE16. Both the thermal and static analyses files (FILE27) were written from FILE16. The IBM data file which generated the thermal and static analyses files appears in Appendix A. The IBM and Cray runstreams which execute the thermal and static analyses are provided in Appendix B.

Table 5 identifies the convection link elements used for the HPOTP preburner pump bearing interfaces and provides the number of elements, material constant, element type, and real constant numbers used for each interface. These elements correspond to the contact and gap conductances given in Section 4, Thermal Environment; that information applies to the thermal analysis only.

Table 6 identifies the radial gap and interference elements used for the HPOTP preburner pump bearing interfaces and provides the clearance, number of elements, element type, and real constant numbers used for each interface. The interface descriptions are schematically presented in Figures 3 and 4. The circled numbers correspond to the interface numbers provided in Table 6.

Table 5 MODEL CONVECTION LINK ELEMENTS

Interface	Elements	Material No.	Type No.	Real No.
Seal/ Support	118	7	7	7 through 48 63 through 138
Seal/ Ring	76	7	7	49 through 62 139 through 200
Seal/ Ring	42	8	8	221 through 262
Seal/ Ring	28	9	9	263 through 290
Isolator/ Isolator Bolts	20	7	7	201 through 220
Isolator/ Support	49	7	7	400 through 448
TOTAL	333			

Table 6 MODEL RADIAL GAP AND INTERFERENCE FITS

Interface	Description	Clearance (in)	Elements	Type No.	Real No.
1	Seal/ Ring	0.001	21	11	333
2	Seal/ Ring	-0.0005	14	11	332
3	Seal/ Ring	0.001	28	11	333
4	Seal/ Support	-0.0015	28	12	331
5	Seal/ Support	0.001	7	12	333
6	Seal/ Notched Head Screw	0.0144	4	12	334
7	Support/ Notched Head Screw	0.0144	2	12	334
8	Ring/ Notched Head Screw	1E-6	4	12	335
9	Support/ Isolator Bolts	1E-6	8	16	335
10	Isolator/ Isolator Bolts	1E-6	8	16	335
TOTAL			124		

Note: Clearance sign follows the ANSYS STIF40 convention, i.e., positive indicates a gap opening and negative indicates interference.

Table 7 identifies the axial gap and interference elements used for the HPOTP preburner pump bearing interfaces. In addition, the clearance, number of elements, element type, and real constant numbers are given for each interface. The interface descriptions are schematically presented in Figures 5 and 6. Again, the circled numbers correspond to the interface numbers provided in Table 7. The gap elements for interfaces 1 through 3 were used as contact elements, while the interference elements for interfaces 4 and 5 were used to preload the bolts. The preload on the bolts was approximated by imposing an interference on the combination element. The bolt preload is further explained in Section 3, Boundary Conditions.

Table 7 MODEL AXIAL GAP AND INTERFERENCE FITS

Interface	Description	Clearance (in)	Elements	Type No.	Real No.
1	Seal/ Ring	1E-6	50	13	333
2	Seal/ Support	1E-6	54	14	335
3	Support/ Isolator	1E-6	25	18	335
4	Ring/ Notched Head Screw	-.0003	24	15	337
5	Support/ Isolator Bolts	-.0002	20	17	338
TOTAL			173		

Note: Clearance sign follows the ANSYS STIF40 convention, i.e., positive indicates a gap opening and negative indicates interference.

3. BOUNDARY CONDITIONS AND LOADS

For the thermal analysis, the boundary conditions on the HPOTP preburner pump bearing model consisted of exterior surface heat transfer coefficients and bulk temperatures, presented in Section 4 of this document, Thermal Environment. The heat transfer coefficients and bulk temperatures were applied as shown in Figure 7.

For the static analysis, the HPOTP preburner pump bearing model was constrained in the translational y direction at $\theta = 0°$ and $\theta = 40°$. In addition, the nodes on the support, where the support bolts are located (not modeled), were constrained in the translational x direction.

The loading on the model for the static analysis consisted of thermal loads obtained from the thermal analysis, pressure loads, and a preload on the bolts. The pressure loads were applied as shown in Figure 8. The bolt preload was approximated by imposing an interference on the axial gap elements located at the isolator bolts/isolator interface and at the notched head screw/seal interface. The interference was calculated from the torque specified in the bolt drawings.

4. THERMAL ENVIRONMENT

Heat transfer coefficients were calculated for the HPOTP preburner pump bearing using the following empirical equations for pipe flow:

for turbulent flow,

$$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$$

and for turbulent flow in a rotating system*

$$h_c = 0.035\ K\ (Re_{ro})^{0.7}\ (Re_s)^{0.1}\ (2a/r_o)^{1.06}\ /2a$$

where

- Nu = Average Nusselt number
- Re = Reynolds number
- Pr = Prandtl number
- K = Thermal conductivity
- Re_{ro} = Rotational Reynolds number $(\rho \omega r_0^2/\mu)$
- Re_s = Source flow Reynolds number $(\dot{W}/4\pi a\mu)$
- r_i = Inner radius of rotating disk
- r_o = Outer radius of rotating disk
- a = Gap distance between rotating and nonrotating disks
- ρ = Fluid density
- μ = Fluid viscosity
- ω = Rotational velocity
- $\dot{W}$ = Flow rate.

*F. Kreith, Advances in Heat Transfer, Vol.5., New York: Academic Press, 1968, p. 192.

Computation of the thermal environment for the HPOTP preburner pump bearing was performed by Gene Teal, LMSC-HEC. Pressures, temperatures, and flow rates for steady state full power level operation were obtained from the Rocketdyne power balance data. In conjunction with the Rocketdyne bearing flow equation and bearing tester data correlation, a pressure drop across the bearings was computed using the coolant flow rate from the power balance data. This pressure drop was then used to calculate the coolant flow rate between the bearing shield and the isolator. Table 8 gives the pressures, temperatures, and heat transfer coefficients at the preburner pump locations shown in Figure 9. Thermal boundary coefficients at locations 20 and 21 are simplifications designed to simulate the outer race to isolator heat fluxes. These data were derived from an analysis performed by Joe Cody of SRS Technologies.

Table 8 THERMAL ENVIRONMENT

Node	Description	P (psia)	T (°R)	hc (Btu/in^2/s/°R)
1	Film Coefficient	350	170	0.0018
2	Film Coefficient	350	240	0.0012
3	Film Coefficient	350	240	0.00021
4	Film Coefficient	400	240	0.00056
5	Film Coefficient	400	240	0.0001
6	Film Coefficient	7000	210	0.017
7	Film Coefficient	3500	235	0.05
8	Contact Conductance	-	-	0.0048
9	Contact Conductance	-	-	0.0048
10	Contact Conductance	-	-	0.0048
11	Contact Conductance	-	-	0.0048
12	Contact Conductance	-	-	0.0048
13	Contact Conductance	-	-	0.0048
14	Contact Conductance	-	-	0.0048
15	Contact Conductance	-	-	0.0048
16	Gap Conductance	7000	-	0.0018
17	Gap Conductance	400	-	0.0015
18	Gap Conductance	7000	-	0.0018
19	Gap Conductance	400	-	0.0015
20	Conductance from Bearing Race to	385	320	0.00024
21	Isolator	365	360	0.00024

5. MATERIAL PROPERTIES

The materials used in the HPOTP preburner pump bearing model components are listed in Table 9. Also listed are the references used for obtaining the material thermal and mechanical properties.

Table 9 MODEL COMPONENT MATERIALS

COMPONENT	MATERIAL	REFERENCE
Isolator	INCONEL 718	Rockwell
Isolator Bolts (2)	AMS 5731 STEEL	Rockwell
Hub Seal	SILVER PLATE	Mil-S-13282 Grade-B
Retainer Ring	MONEL BAR	Rockwell
Notched Head Screw	A286 STEEL	Rockwell
Support	INCONEL 718	Rockwell

INCONEL 718 material property data, obtained from the Rockwell Materials Properties Manual, were curve fitted to cubic polynomials for ANSYS input over the temperature range of 0 to 2000 °R. Extrapolation beyond 2000 °R is questionable. However, the expected temperature range for this analysis is from 100 to 1500 °R, well within the selected curve fit limits. Figure 10 shows the coefficient of thermal conductivity as a function of absolute temperature. Young's modulus, Poisson's ratio, and the coefficient of thermal expansion for INCONEL 718 as functions of absolute temperature are presented in Figures 11, 12, and 13, respectively.

In addition, the following material properties for the A286 steel bolts are used:

Coefficient of Thermal Conductivity (k) = 8.68 Btu/in/°R

Young's Modulus (E) = 29.1×10^{6} lbf/in^{2}

Poisson's Ratio (ν) = 0.29

Coefficient of Thermal Expansion (α) = 0.917×10^{-5} in/in/°R

These are assumed constant over the absolute temperature range from 0 to 2300 °R.

6. THERMAL ANALYSIS

The nonlinear thermal analysis performed on the HPOTP preburner pump bearing model converged in three iterations using the automatic ANSYS convergence criterion of 1°. Temperature distributions for cross sections of the model at $\theta = 0°$ and at $\theta = 20°$ are shown in Figures 14 and 15, respectively. The thermal distribution at these cross sections is representative of the thermal distribution in the rest of the model. Large thermal gradients occur at the isolator/bearing race interface. The thermal analysis results are used for nodal temperature input to the structural analysis presented in Section 7.

7. STRUCTURAL ANALYSIS/RESULTS

A static analysis was performed on the HPOTP preburner pump bearing model to determine the radial deflection of the isolator under the load case described in Section 3, Boundary Conditions and Loads.

Exaggerated deformation plots of the isolator at cross sections $\theta = 0°$ and $\theta = 20°$ are shown in Figures 16 and 17. Dashed lines on the deformation plots represent the undeformed structure. Listed in Tables 10 and 11 are the radial deflection of the isolator nodes above bearings 1 and 2, respectively.

Table 10 RADIAL DEFLECTIONS OF ISOLATOR NODES ABOVE BEARING 1

THETA	NODES	RADIAL DEFLECTION (in.)
	1	-0.002706
	5	-0.002754
0°	6	-0.002779
	7	-0.002790
	4	-0.002780
	17	-0.002706
	20	-0.002754
6°	21	-0.002779
	22	-0.002789
	19	-0.002780
	188	-0.002706
	191	-0.002754
14°	192	-0.002779
	193	-0.002789
	190	-0.002780
	329	-0.002706
	332	-0.002754
20°	333	-0.002779
	334	-0.002789
	331	-0.002779
	2188	-0.002706
	2191	-0.002754
26°	2192	-0.002779
	2193	-0.002789
	2190	-0.002780
	2017	-0.002706
	2020	-0.002754
34°	2021	-0.002779
	2022	-0.002789
	2019	-0.002780
	2001	-0.002706
	2005	-0.002754
40°	2006	-0.002779
	2007	-0.002790
	2004	-0.002780

Table 11 RADIAL DEFLECTIONS OF ISOLATOR NODES ABOVE BEARING 2

THETA	NODES	RADIAL DEFLECTION (in.)
0°	32	-0.002758
	31	-0.002722
	44	-0.002665
	45	-0.002590
	43	-0.002496
6°	38	-0.002758
	37	-0.002722
	53	-0.002665
	54	-0.002590
	52	-0.002496
14°	244	-0.002757
	243	-0.002722
	250	-0.002665
	251	-0.002590
	249	-0.002496
20°	344	-0.002757
	343	-0.002722
	350	-0.002665
	351	-0.002590
	349	-0.002496
26°	2244	-0.002757
	2243	-0.002722
	2250	-0.002665
	2251	-0.002590
	2249	-0.002496
34°	2038	-0.002758
	2037	-0.002722
	2053	-0.002665
	2054	-0.002590
	2052	-0.002495
40°	2032	-0.002758
	2031	-0.002722
	2044	-0.002665
	2045	-0.002590
	2043	-0.002495

8. CONCLUSIONS AND RECOMMENDATIONS

The static analysis of the HPOTP preburner pump bearing assembly shows that the isolator deflects inward due to the operating environment. The assembly clearance between the isolator and the bearing outer races is 0.0024 in. The maximum radial displacement of the isolator is 0.00279. No conclusions can be drawn from this since the bearing deflection is not known at the operational level.

In a further analysis, the stiffness of the outer bearing races and the stiffness of the preburner pump housing should be included in the model.

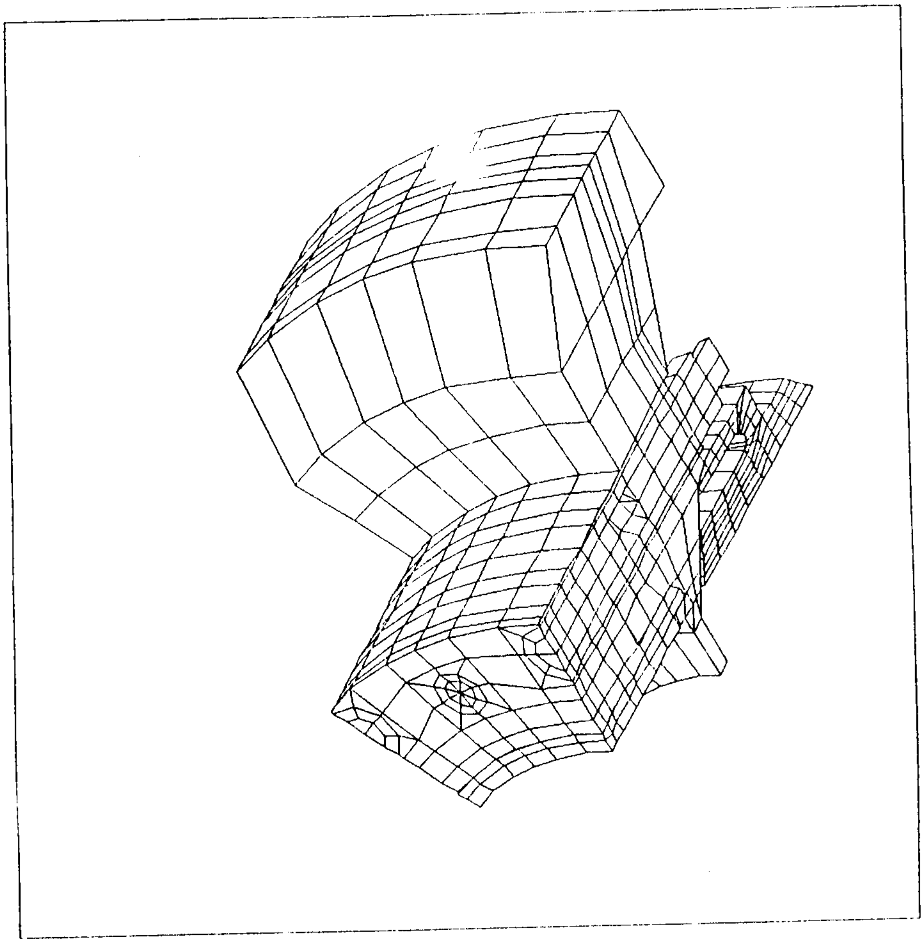

Figure 1 HPOTP Preburner Pump Bearing Model

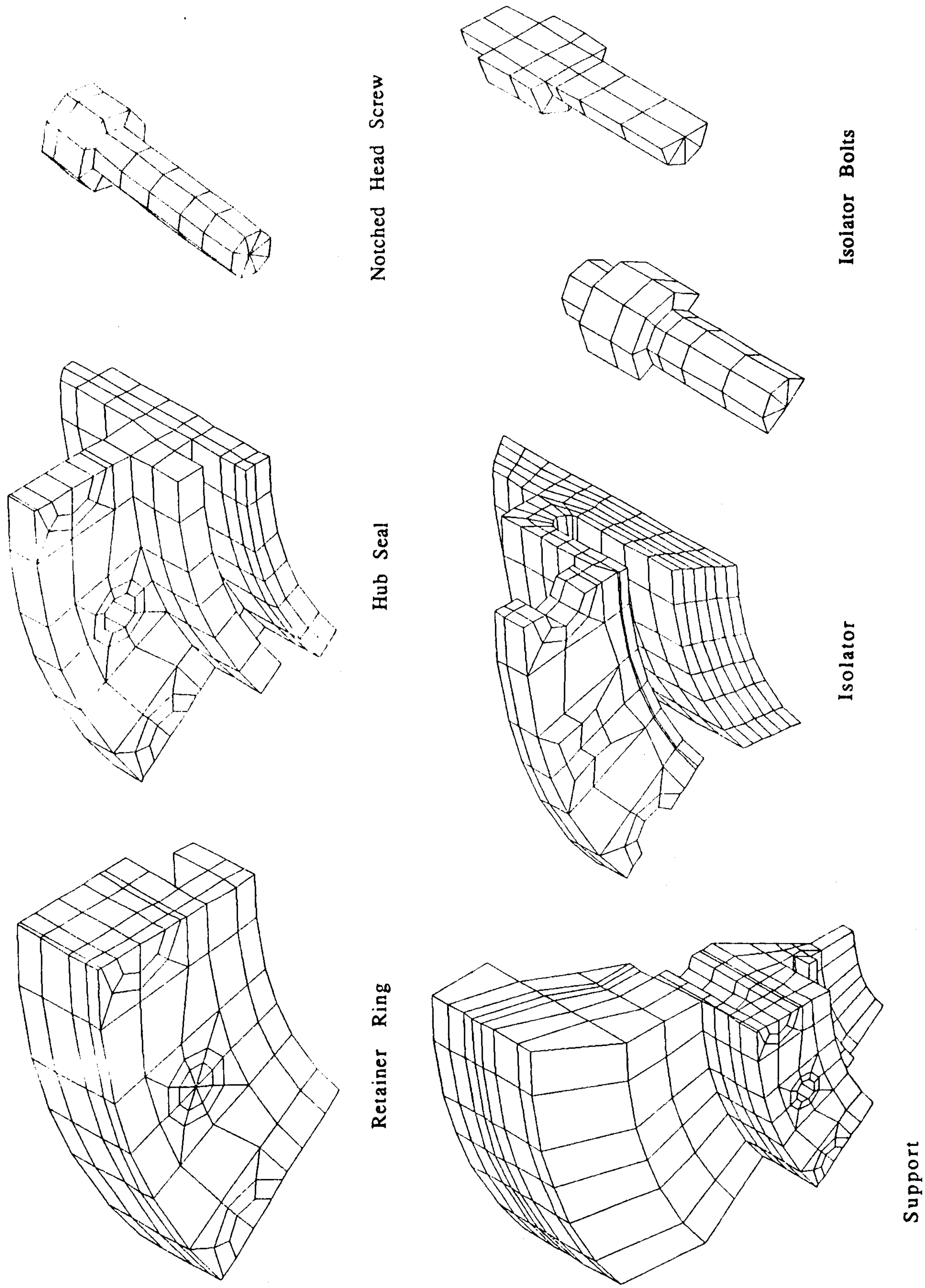

Figure 2 Cutaway Views of Model Components

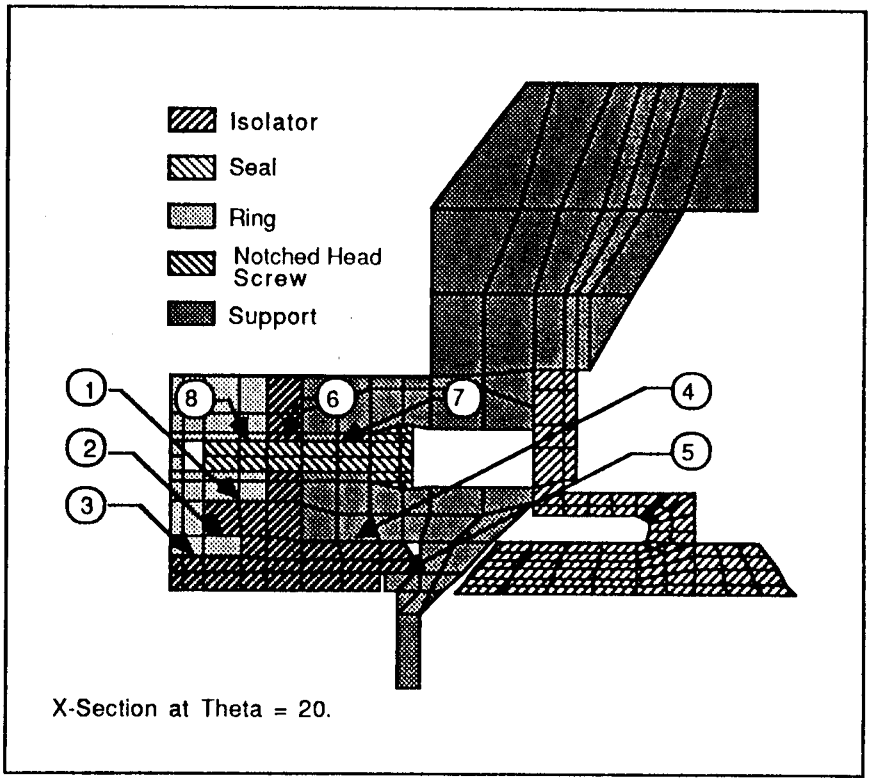

Figure 3 Schematic of Radial Interfaces 1 through 8

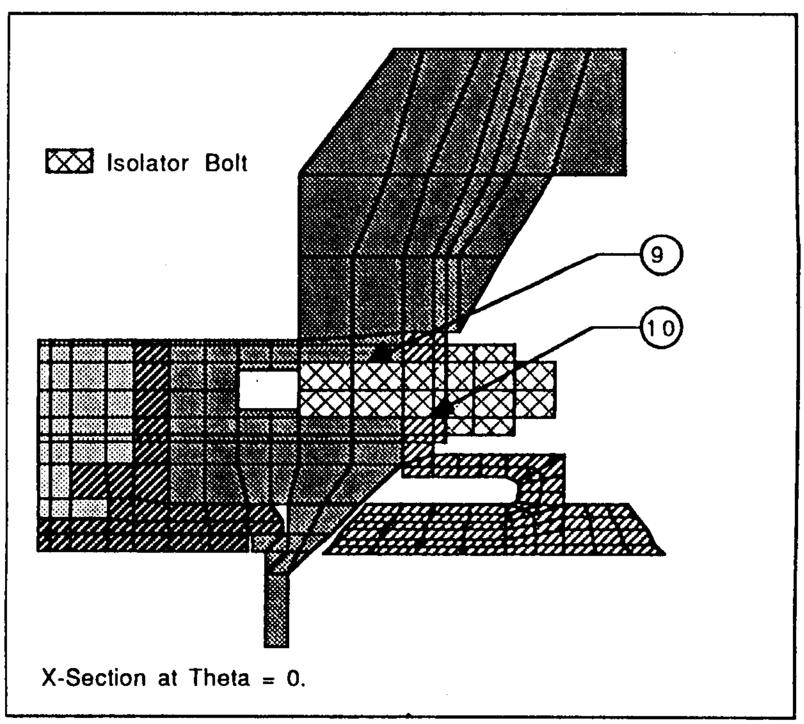

Figure 4 Schematic of Radial Interfaces 9 and 10

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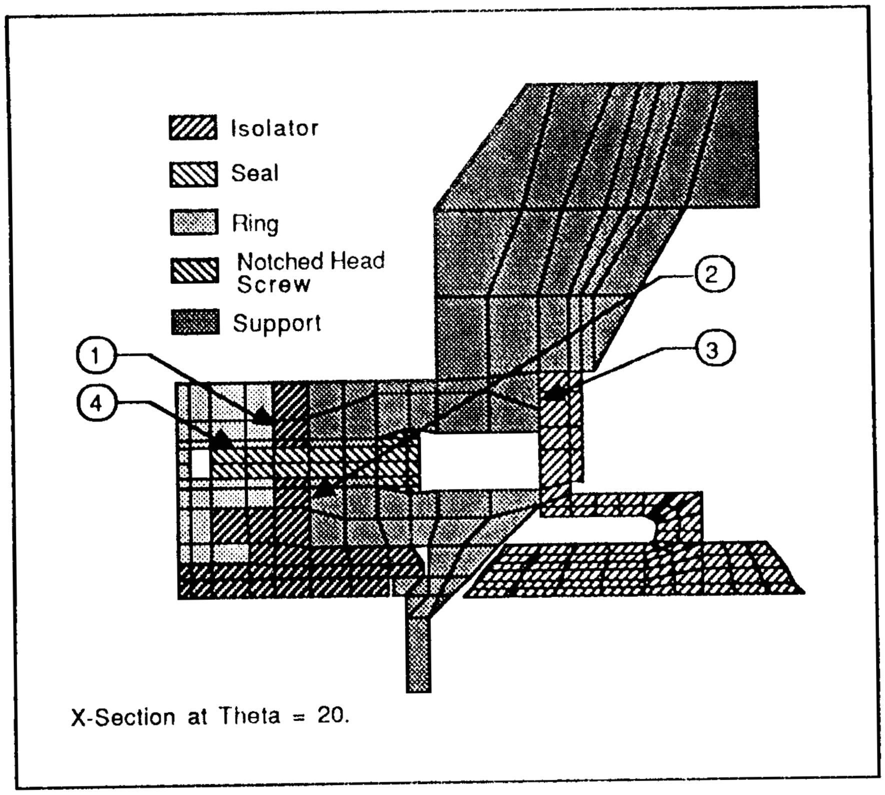

Figure 5 Schematic of Axial Interfaces 1 through 4

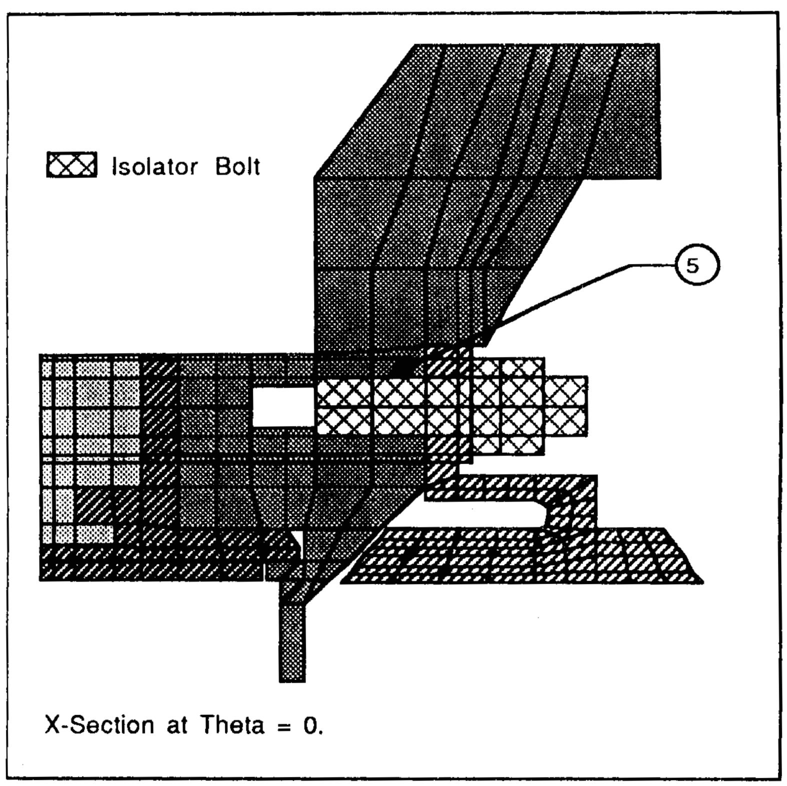

Figure 6 Schematic of Axial Interface 5

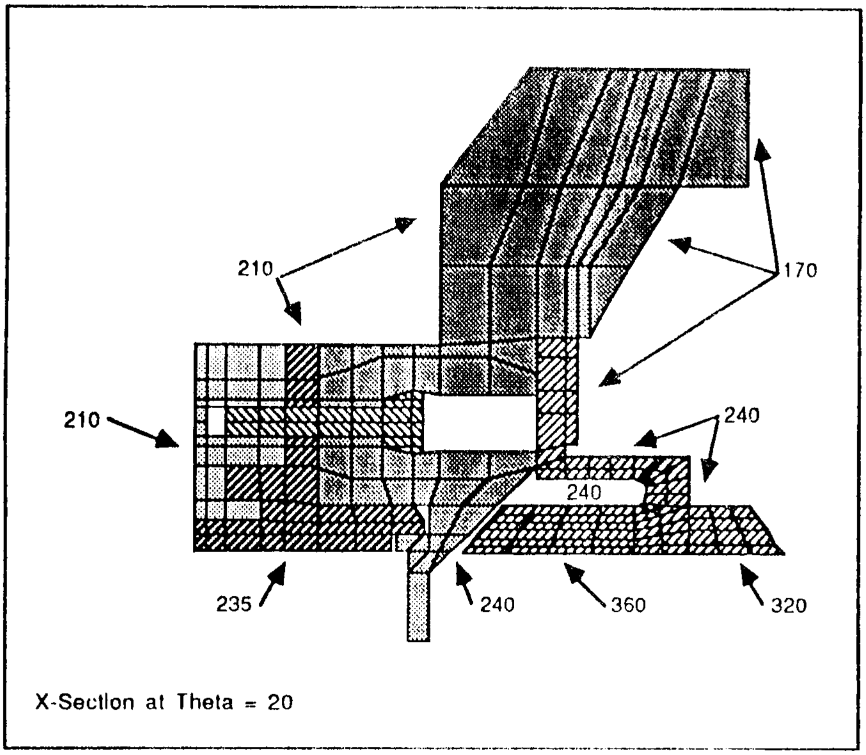

Figure 7 Bulk Temperatures (°R) Applied to Model

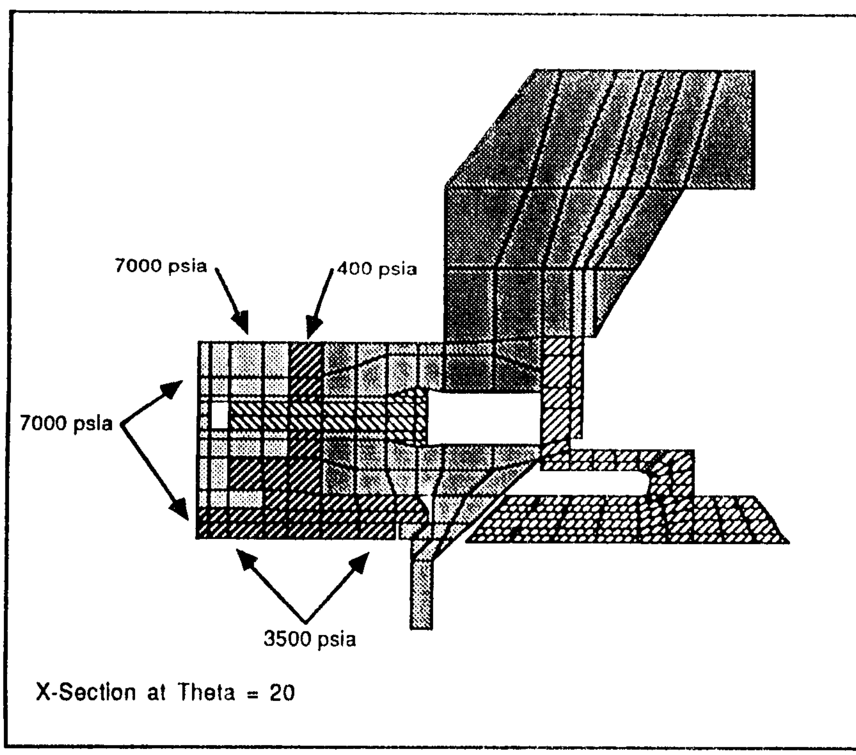

Figure 8 Pressure Applied to Model

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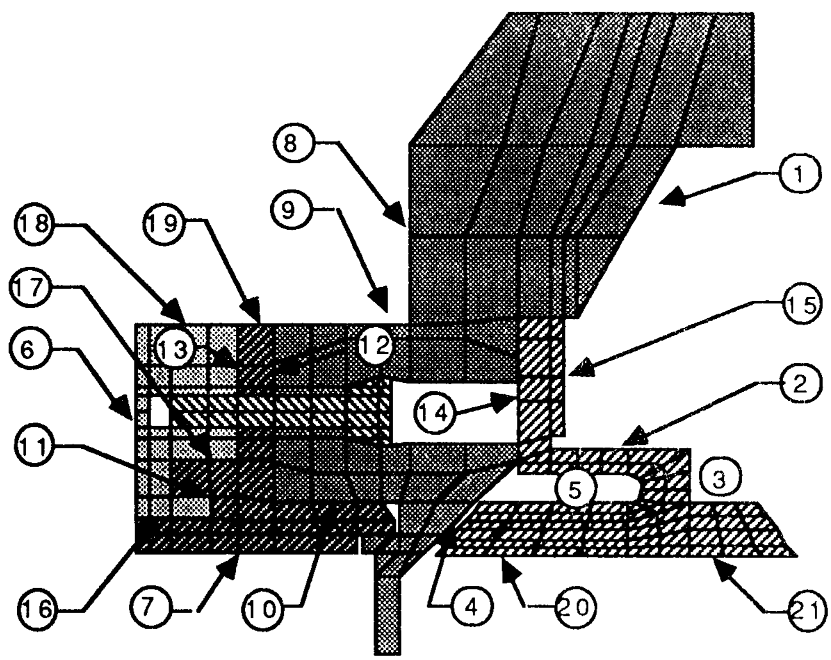

HPOTP Preburner Pump Bearing
Thermal Environment Schematic

Figure 9 Thermal Environment Schematic

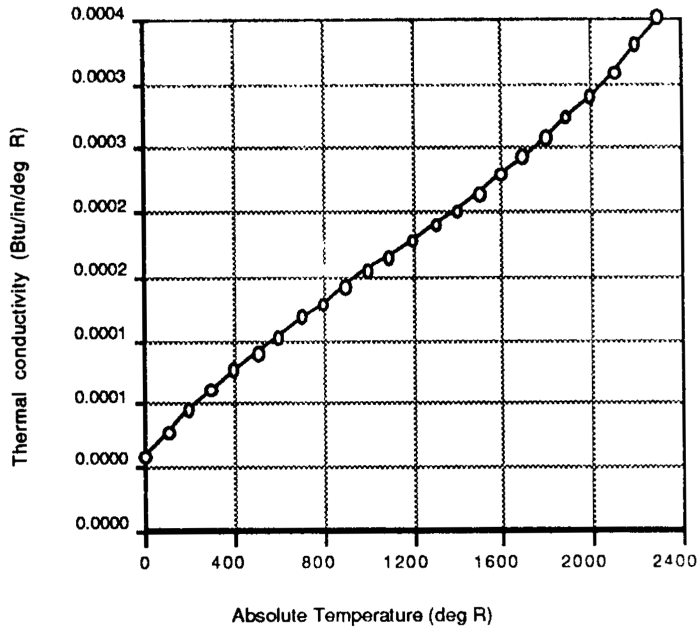

Figure 10 INCONEL 718 Coefficient of Thermal Conductivity as a Function of Absolute Temperature

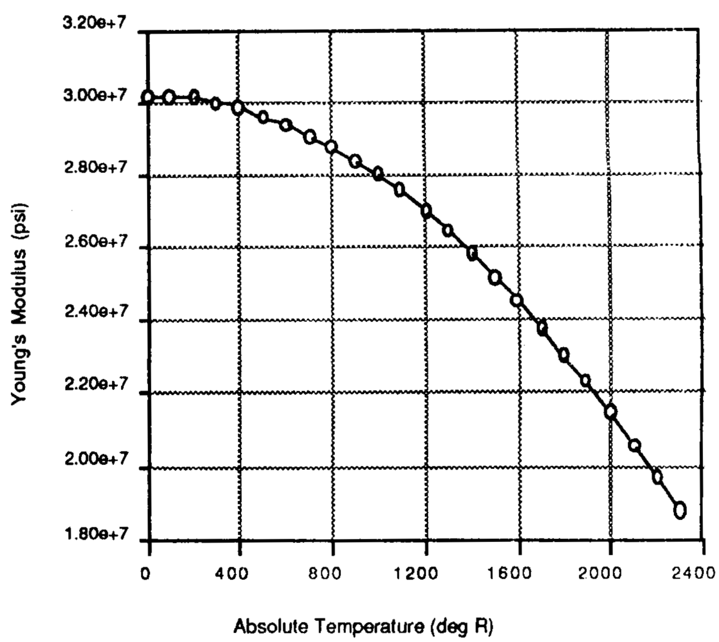

Figure 11 INCONEL 718 Young's Modulus as a Function of Absolute Temperature

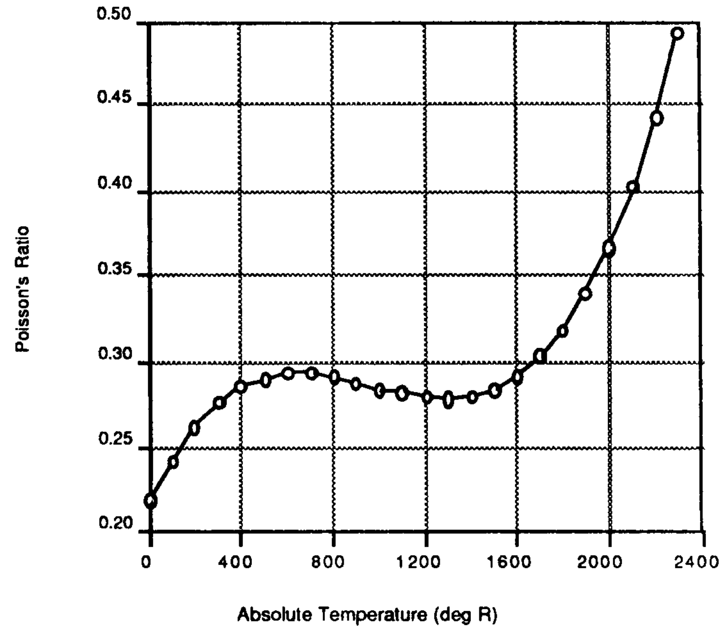

Figure 12 INCONEL 718 Poisson's Ratio as a Function of Absolute Temperature

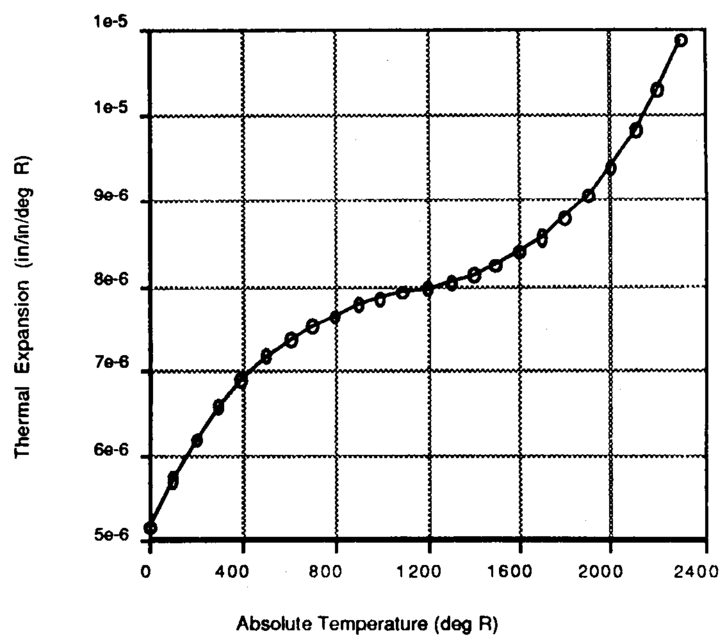

Figure 13 INCONEL 718 Coefficient of Thermal Expansion as a Function of Absolute Temperature

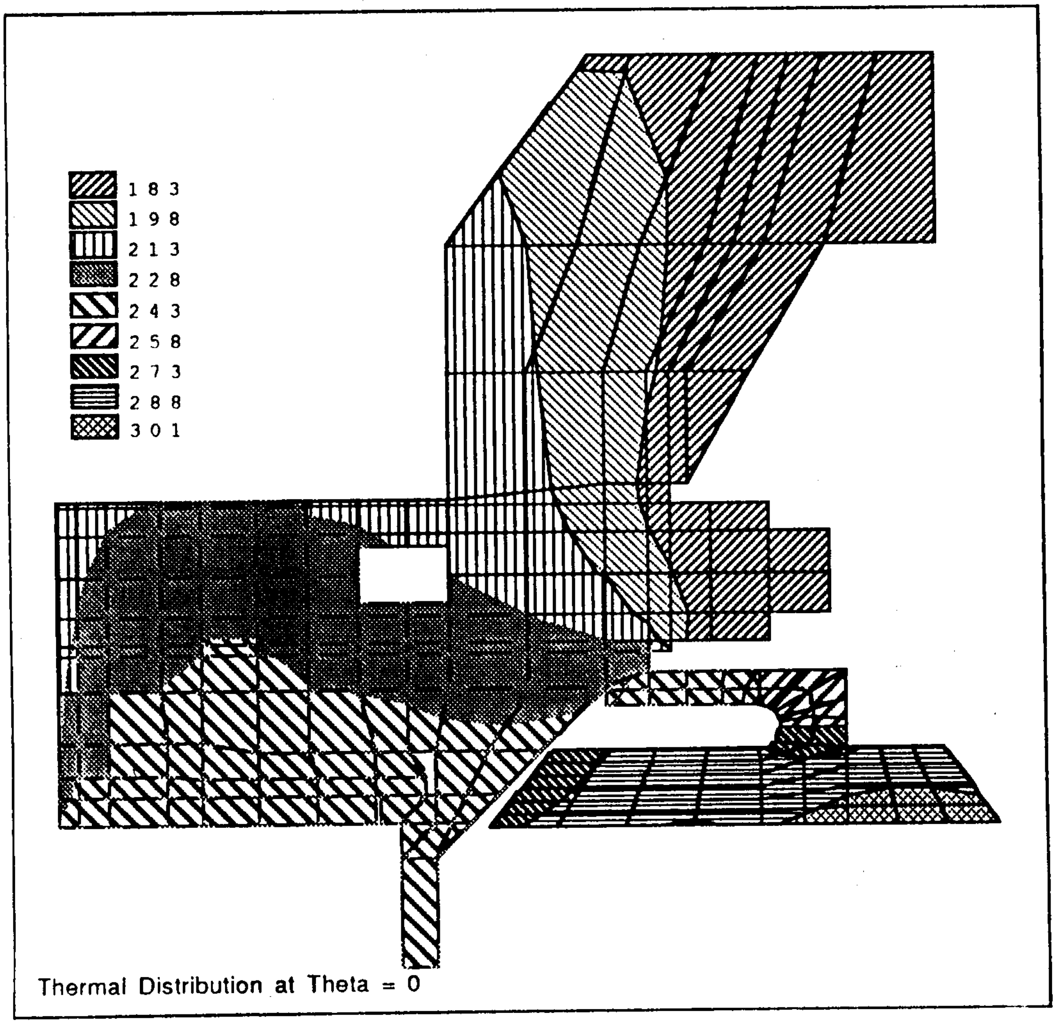

Figure 14 Temperature Distribution Plot for Cross Section at $\theta = 0°$

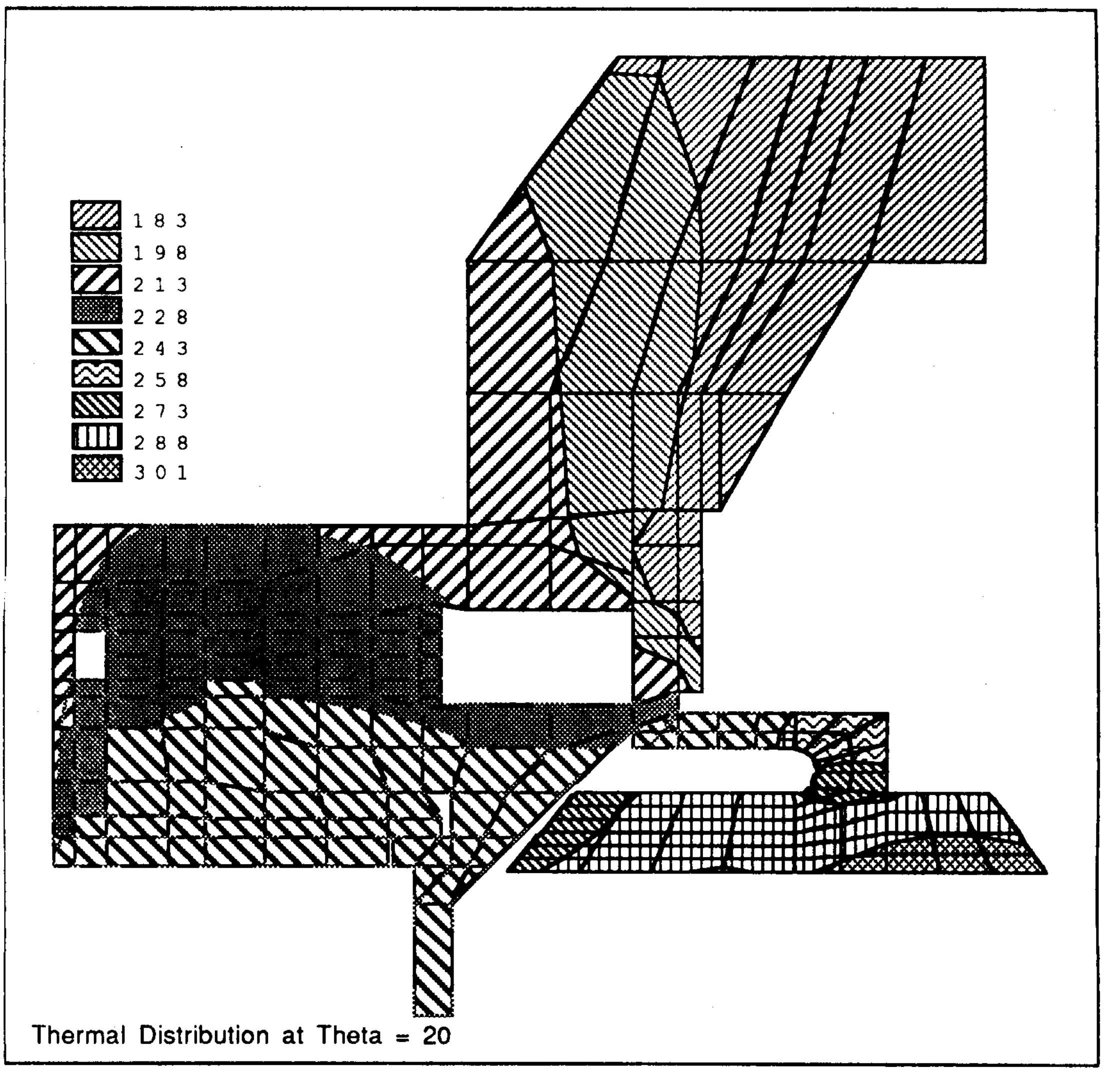

Figure 15 Temperature Distribution Plot for Cross Section at $\theta = 20°$

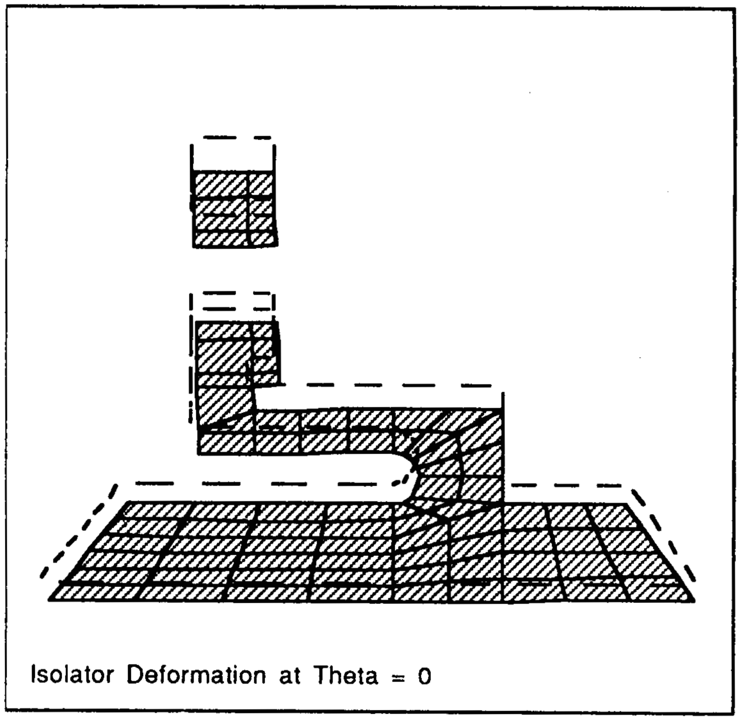

Figure 16 Deformation Plot of Isolator at $\theta = 0°$

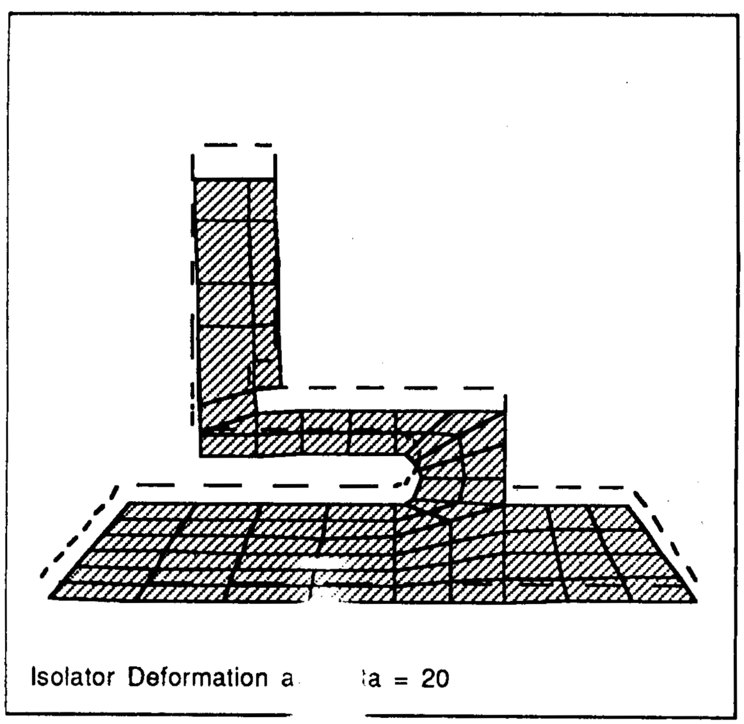

Figure 17 Deformation Plot of Isolator at $\theta = 20°$

Appendix A

IBM DATA FILE FOR ANALYSES

DATA INPUT FOR STATIC ANALYSIS

```
/CORE,3E6
/PREP7
C***
RESUME
/TITLE,STATIC ANALYSIS
KAN,0
CSYS,1
C***
C*** SET CONVECTION LINK ELEMENTS TO NULL ELEMENTS
C***
ET,7,0
RP3,1
C***
C*** SET ELEMENT TYPES 11 THRU 18 TO STIF40
C***
ET,11,40
RP2,1
ET,13,40,,,3
RP3,1
ET,16,40
ET,17,40,,,3
RP2,1
C***
C*** DELETE ELEMENT CONVECTIONS AND TEMPERATURE NODE COUPLING
C***
CVDELE,ALL
CPDELE,401,508
C***
EALL
NALL
KTEMP,1,10
ITER,-40,40,40
AFWRITE
/EOF
```

DATA INPUT FOR THERMAL ANALYSIS

```
/CORE,3E6
/PREP7
C***
/RESUME
/TITLE, THERMAL ANALYSIS
C***
KAN,-1
C***
C*** SET GAP ELEMENTS (STIF40'S) TO NULL ELEMENTS
C*** FOR THERMAL ANALYSIS
C***
ET,11,0
RP8,1
C***
C*** SET ELEMENT TYPES 7 THRU 9 TO STIF34
C***
ET,7,34
RP3,1
C*** DELETE ELEMENT PRESSURES, STRUCTURAL NODE COUPLING AND
C*** IMPOSED DISPLACEMENTS
EPDELE,ALL,,,ALL
CPDELE,1,347
DDELE,ALL,ALL
C***
EALL
NALL
KBC,1
ITER,-10,10,10
AFWRITE
/EOF
```

Appendix B
IBM AND CRAY RUNSTREAMS

IBM RUNSTREAM FOR STATIC ANALYSIS

```
// MSGCLASS=X
//DELETE EXEC PGM=IEFBR14
//F1  DD DISP=(MOD,DELETE),UNIT=SYSDA,
//       SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.HPOTPNS.FILE27
//F2  DD DISP=(MOD,DELETE),UNIT=SYSDA,
//       SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.HPOTPNS.FILE21
//F3  DD DISP=(MOD,DELETE),UNIT=SYSDA,
//       SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.HPOTPNS.FILE19
//*
//ANSYS43 EXEC ANSYS43,C=CATLG,
//       F19='CCDJ202.ANSYS.HPOTPNS.FILE19',
//       F21='CCDJ202.ANSYS.HPOTPNS.FILE21',
//       F27='CCDJ202.ANSYS.HPOTPNS.FILE27',
//GO.FILE04  DD DSN=CCDJ202.ANSYS.HPOTPN.FILE04,
//       DISP=(OLD,KEEP),
//       DCB=(RECFM=VBS,LRECL=4652,BLKSIZE=4648)
//GO.FILE16  DD DSN=CCDJ202.ANSYS.HPOTPNS.FILE16,
//       DISP=(OLD,KEEP),
//       DCB=(RECFM=VBS,LRECL=5004,BLKSIZE=5008)
//GO.FILE18  DD UNIT=SYSDA,SPACE=(4642,(3000,500)),
//       DISP=(NEW,CATLG,DELETE),
//       DCB=(RECFM=FB,LRECL=80,BLKSIZE=4000)
//GO.FILE19  DD SPACE=(4642,(3000,500),RLSE),DISP=(NEW,CATLG)
//GO.FILE27  DD SPACE=(4652,(3000,500),RLSE),DISP=(NEW,CATLG)
//GO.FT05F001  DD DSN=CCDJ202.HPOTPNS.DATA(STATIC),
//       SPACE=(4096,(9000,1500),RLSE),DISP=SHR
//
```

IBM RUNSTREAM FOR THERMAL ANALYSIS

```
//  MSGCLASS=X
//DELETE EXEC PGM=IEFBR14
//F1  DD DISP=(MOD,DELETE),UNIT=SYSDA,
//       SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.HPOTPN.FILE27
//F2  DD DISP=(MOD,DELETE),UNIT=SYSDA,
//       SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.HPOTPN.FILE21
//F3  DD DISP=(MOD,DELETE),UNIT=SYSDA,
//       SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.HPOTPN.FILE19
//*
//ANSYS43 EXEC ANSYS43,C=CATLG,
//       F19='CCDJ202.ANSYS.HPOTPN.FILE19',
//       F21='CCDJ202.ANSYS.HPOTPN.FILE21',
//       F27='CCDJ202.ANSYS.HPOTPN.FILE27'
//GO FILE16  DD DSN=CCDJ202.ANSYS.HPOTPNS.FILE16,
//       DISP=(OLD,KEEP),
//       DCB=(RECFM=VBS,LRECL=5004,BLKSIZE=5008)
//GO.FILE18  DD UNIT=SYSDA,SPACE=(4642,(3000,500)),
//       DISP=(NEW,CATLG,DELETE),
//       DCB=(RECFM=FB,LRECL=80,BLKSIZE=4000)
//GO.FILE19 DD SPACE=(4642,(3000,500),RLSE),DISP=(NEW,CATLG)
//GO FILE27  DD SPACE=(4652,(3000,500),RLSE),DISP=(NEW,CATLG)
//GO FILE28 DD DSN=CCDJ202.ANSYS.GEOM.FILE28,DISP=(OLD,KEEP),
//       DCB=(RECFM=FB,LRECL=80,BLKSIZE=6320)
//GO FT05F001  DD DSN=CCDJ202.HPOTPN.DATA(THERMAL),
//       SPACE=(4096,(9000,1500),RLSE),DISP=SHR
//
```

CRAY RUNSTREAM FOR STATIC ANALYSIS

```
JOB,JN=CCDJ202,MFL=2500000,T=1000.
ACCOUNT,AC=6ED554590417,US=CCDJ202.
FETCH,DN=FT27,TEXT='DSN=CCDJ202.ANSYS.HPOTPNS.FILE27,DISP=SHR'.
FETCH,DN=FT04,DF=TR,TEXT='DSN=CCDJ202.ANSYS.HPOTPN.FILE04,DISP=SHR'.
ACCESS,DN=ANSYS,PDN=SOL43N,ID=ANSYS43,OWN=SYSTEM.
ACCESS,DN=AUTH43,ID=ANSYS43,OWN=SYSTEM. ACCESS AUTHORIZATION FILE
MODE,BT=DISABLE.
ANSYS.
SAVE,DN=FT14,PDN=HPOTPN14.
DISPOSE,DN=FT14,DC=ST,TEXT='DSN=CCDJ202.ANSYS.HPOTPNS.FILE14,'^
    'DISP=(,CATLG),'^
    'SPACE=(CYL,(20,2),RLSE),'^
    'DCB=(RECFM=FB,BLKSIZE=6320,LRECL=80)',WAIT.
/EOF
/CORE,2.0E6
/INPUT,27
FINISH
/AUX1
BCDCNV
FINISH
```

CRAY RUNSTREAM FOR THERMAL ANALYSIS

```
JOB,JN=CCDJ202,MFL=2500000,T=2500.
ACCOUNT,AC=6ED554590417,US=CCDJ202.
FETCH,DN=FT27,TEXT='DSN=CCDJ202.ANSYS.HPOTPN.FILE27'.
ACCESS,DN=ANSYS,PDN=SOL43N,ID=ANSYS43,OWN=SYSTEM.
ACCESS,DN=AUTH43,ID=ANSYS43,OWN=SYSTEM. ACCESS AUTHORIZATION FILE
MODE,BT=DISABLE.
ANSYS.
DISPOSE,DN=FT04,DC=ST,DF=TR,TEXT='DSN=CCDJ202.ANSYS.HPOTPN.FILE04,'^
    'DISP=(,CATLG),'^
    'SPACE=(CYL,(60,10),RLSE),'^
    'DCB=(RECFM=VBS,BLKSIZE=4648,LRECL=4652)',WAIT.
SAVE,DN=FT14,PDN=HPOTP14.
DISPOSE,DN=FT14,DC=ST,TEXT='DSN=CCDJ202.ANSYS.HPOTPN.FILE14,'^
    'DISP=(,CATLG),'^
    'SPACE=(CYL,(20,2),RLSE),'^
    'DCB=(RECFM=FB,BLKSIZE=6320,LRECL=80)',WAIT.
/EOF
/CORE,2.0E6
/INPUT,27
FINISH
/AUX1
FINISH
/AUX1
BCDCNV
FINISH
```